The drivers spine analytical model

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***Abstract*—**The paper presents the determination of the analytical expression in the coronal plane of the drivers spine while driving along curved roads. Further on the analytical expression is used to determine ergonomic parameters for the car seat design. The analytical expression is determined by developing an experiment to monitor the position variation in time of the vertebras in the sagittal and coronal plane. The results lead to three sinusoidal equations of which amplitude values describing the variation in time of angles between the vertebras gives an image regarding the deformation degree of the intervertebral discs.

***Keywords*—**Spine, ergonomics, vehicle, musculoskeletal affections.

I. Introduction

THE possibility to drive in complete healthy and safety conditions not only for the professional drivers but also for the rest of the population which uses vehicles as frequent transportation means leads to efficiency by improving the quality of life.

In this context it is noted the following objectives and research directions: the development of modern mathematical models and principles to be included in a design or control algorithm.

The ergonomic optimal body posture of the driver sitting in the car seat, is influenced by the structural and design characteristics of the seat. The seat has to constrain the body so that the spine form takes the anatomical ideal or the ergonomic optimal shape.

Therefor to design an ergonomic car seat it is proposed to start from the ideal anatomical shape of the spine in the sagittal and coronal plane.

The present study is based on the ergonomics research regarding the spine's behavior while driving along curved roads.

II. Analytical expression of the spine in the sagittal plane

In order to determine the design parameters of the car seat it is necessary to know the analytical shape of the spine in sagittal plane and coronal plane.

The analytical expression of the spine in sagittal plane in standing position is:

$$y = \frac{1}{L}\left(\frac{m}{6}-\frac{A}{3}\right)\cdot x^3 + A\cdot x^2 - L\cdot\left(\frac{m}{6}-\frac{2\cdot A}{3}\right)\cdot x + \frac{R}{L}\cdot x + \left(\frac{m}{6}-\frac{2\cdot A}{3}\right)\cdot\frac{L^2}{\pi}\cdot sin\frac{\pi\cdot x}{L} - \frac{R}{L}\cdot sin\frac{\pi\cdot x}{L} \quad (1)$$

L and R are x, y coordinates of the point L5-S1 from figure 1.

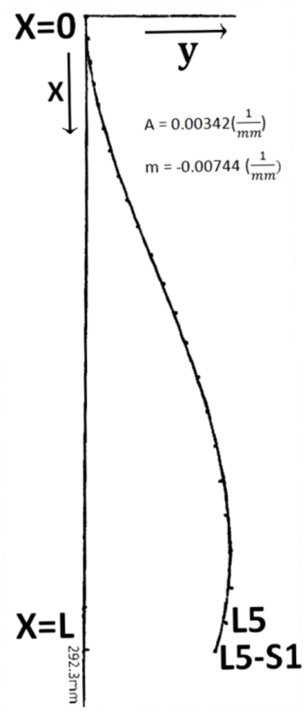

Fig. 1. The spine analytical shape in the sagittal plane in standing position.

From the analysis of 30 X-Rays have been obtained values for A parameter between 0.00003mm^{-1} and 0.00005mm^{-1} and for the m parameter values between 0.00005mm^{-1} and 0.0015mm^{-1}. These values are for the erect position of the spine.

According to international standards, the correct posture while driving is achieved by placing the trunk in such a way that the angle between it and the thigh reach 110° - 120° (Fig. 2).

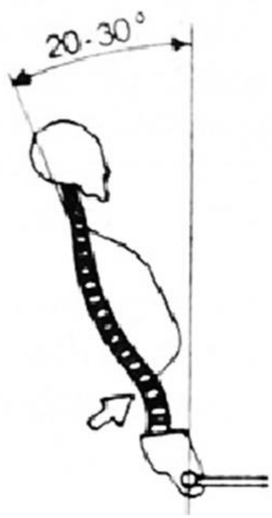

Fig. 2. The correct seated position while driving.

Using the MathCAD software the spine form in seated position was determined based on the HP (hip point) point coordinates and the line that contains the HP point and represents the spine inclination according to International Standard ISO 3958-1977.

The line equation in the xOy coordinate system presented in figure 1, is:

$$incl(x) = tg(\beta) \cdot (x - x_{HP}) + y_{HP} \quad (2)$$

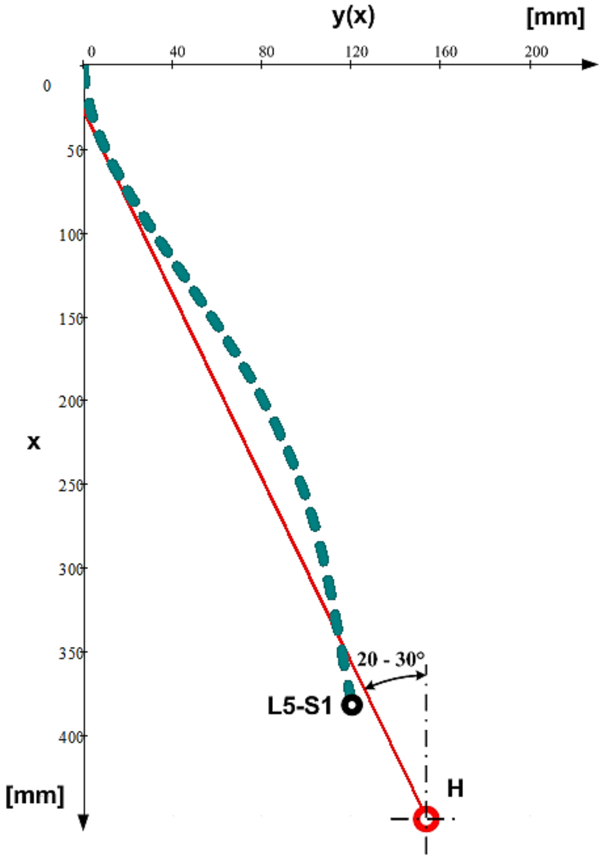

Fig. 3. The spine analytical shape in the sagittal plane in seated position.

For the seated position the values are: $A=0.00004mm^{-1}$ and $m=0.0016mm^{-1}$.

III. Analytical Expression of the Spine in the Coronal Plane

The optimal ergonomic body posture of the driver sitting in the car seat is influenced by the structural characteristics of the seat. The body has to be constrained to the seat such way so that the spine's form is an ideal anatomical or ergonomic optimal shape. Therefore to design and construct the car seat, it is proposed to start from the ideal anatomical shape of the spine in the coronal plane (Fig. 4). [2, 3]

To determine the design parameters of the car seat is necessary to know the analytical form of the spine's shape in the coronal plane.

In the coronal plane, the shape of the spine can be expressed mathematically by the equation of a straight vertical line. Vertebrae centers are collinear. Considering a reference system as in figure 2, the vertical line's equation containing vertebras centers is considered to be x = 0.

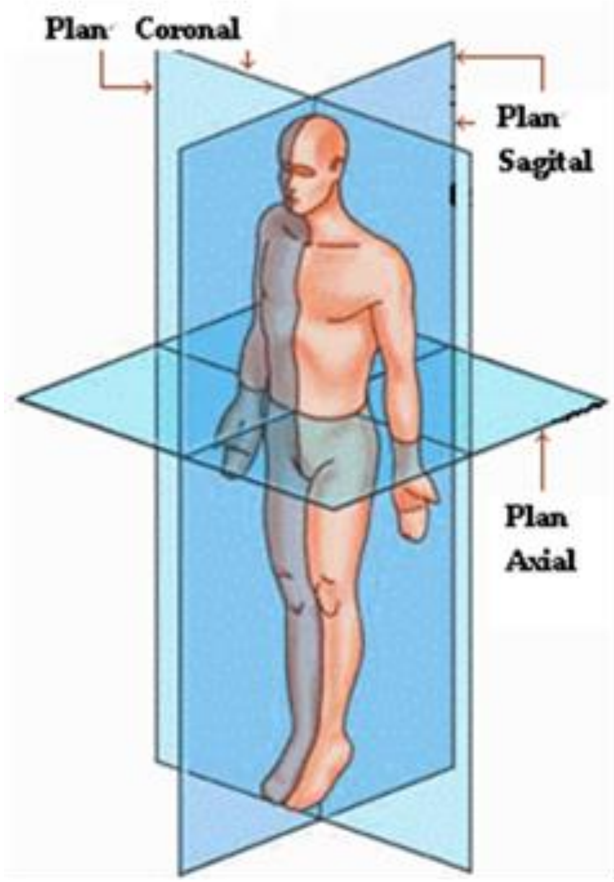

Fig. 4. Anatomical planes.

Point O, the origin of the coordinate system coincides with the lowest point of the coccyx.

The analytical expression x = 0 of the spine's shape in the coronal plane is only valid if the vehicle is at rest, or the vehicle travels on a rectilinear continuous road (unreal case).

Due to the centrifugal force acting on the human body while the vehicle is traveling along a, the human body changes its posture in the coronal plane in the opposite direction of the centrifugal force, to maintain the balance in the car seat. Thus the spine's shape changes depending on the vehicle's traveling speed and the curved path's radius, causing the spine shape mathematical expression in the coronal plane to be a motion law.

The spine shape is the line containing the centers of the vertebras. Anatomically, the shape and movement of the spinal column are shown by the relative rotational movement between the vertebras. According to anatomy and kinematic studies of the human spine, it is concluded that the center of rotation between two vertebras is the center of the intervertebral disc that connects the two vertebras. Thus intervertebral disc can be considered a ball joint with three degrees of freedom corresponding to rotation after three axes.

In figure 3 are shown as an example, L3 and L4 vertebras centers as CL3 and CL4 points, and the rotation centers of the L2, L3, L4 and L5 vertebras, as CrL2-L3-L4 and CrL4 CrL3-L5.

Fig. 5. The spine in the coronal plane related to the coordinate system xOy.

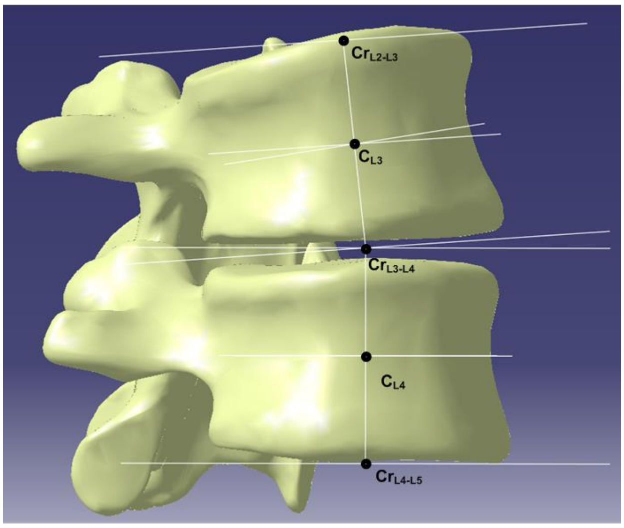

Fig. 6. L3 and L4 vertebras centers (CL3 and CL4), and the rotation centers of the L2, L3, L4 and L5 vertebras (CrL2-L3-L4 and CrL4 CrL3-L5).

Considering the vertebras in the coronal plane as represented by segments connecting the rotation centers, the shape of the spine may be given by the angles α_i of these segments.

Figure 4 represents the lumbar segment in the coronal plane. The L1, L2 ... L5 vertebras are the CrT12-L1CrL2-L3-L3 CRL1-L2CrL2, CrL2-L3CrL3-L4-S1 ... CrL4-L5CrL5 segments. The relative rotation between two vertebras is given by the angle α_i between the segments representing the two vertebras.

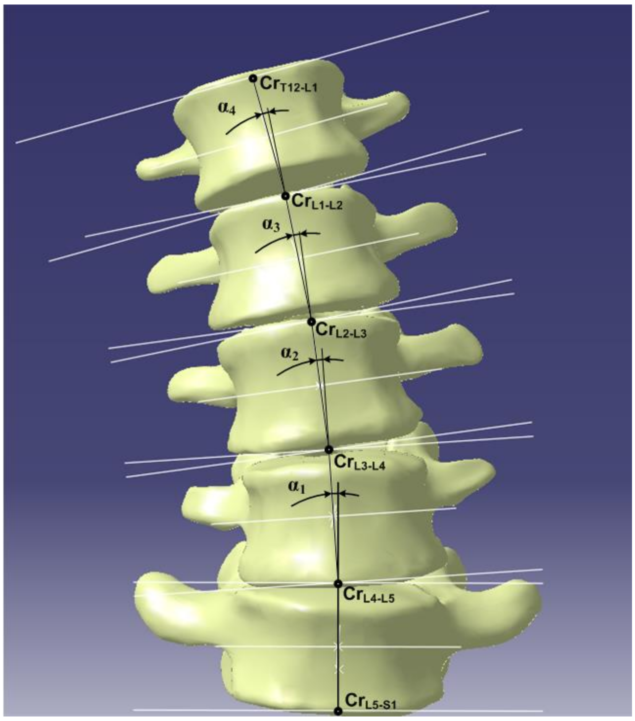

Fig. 7. The lumbar spine with the segments representing L1, L2 ... L5 vertebras.

The motion law of the spine in the coronal plane can be expressed as a function of the vehicle speed (v_a), the curved trajectory radius (r_{tr}) and the upper body mass (m_{cs}), function that returns the values of the α_i angles.

$$f(v_a, r_{tr}, m_{cs}) \rightarrow \alpha_i \tag{3}$$

To determine the function given by relation (3), we created an experiment that for a given route and a constant driving speed, the upper body movements in the coronal plane were monitored.

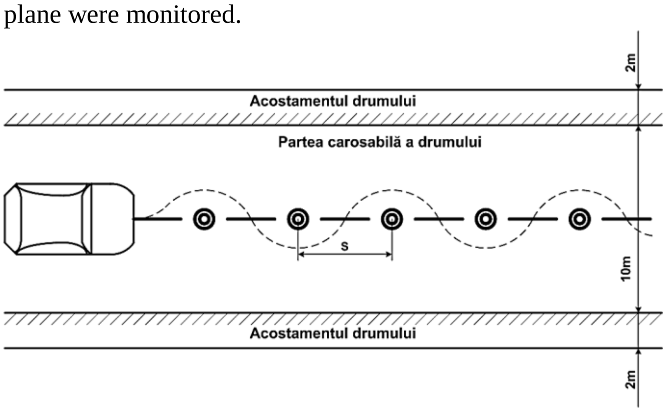

Fig. 8. The route used in the experiment.

The track used in the experiment is the same track used to determine the dynamic cornering ability of the vehicles (fig. 8).[29]

In the experiment we used the motion sensor manufactured by *PASCO scientific* and the PASCO CI-6400 Science Workshop 500 Interface (fig. 10).

The motion sensor MotionSensor II (fig. 9) operates on the sonar principle. The sensor can measure distances between 0.15m and 8m, between it and the object of interest (fig. 9).

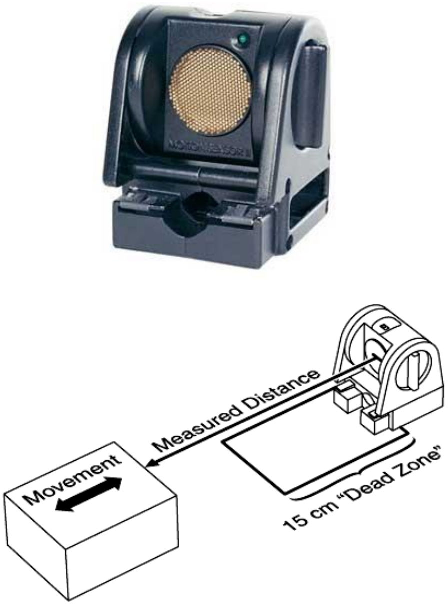

Fig. 9. Motion Sensor II.

Fig. 10. PASCO CI-6400 Science Workshop 500 Interface.

Before measurements, the motion sensor must be calibrated.

In this experiment the driver's upper body sideway movements in the coronal plane were monitored. To monitor the movements in the coronal plane the motion sensor was used to determine the positions in time of three points on the driver's body right side. In figure 11 is shown the positioning of the sensor. The first point is on the right side of the C1 vertebra, located at a distance of d_C = 0.477m from the sensor. The second point is placed on the right shoulder on the T4 vertebra’s right side, located at a distance of d_T = 0.39m from the sensor. The third point is located next to the L1 vertebra located at a distance of d_L = 0.419m from the sensor.

In figure 12 is shown the sensor in the first position for determining the C1 vertebra movements. The r_C, r_T and r_L distances from the seat surface, were determined by anthropometric measurements of the driver’s body in seated position. Thus r_C = 0.8m, r_T = 0.585m and r_L = 0.4m.

The experiment was carried out in three stages. In each stage the position in time of one of the three points is determined. In each stage the vehicle is traveling with a constant speed of 15km/h according to the vehicle dynamic steering ability tests. [5]

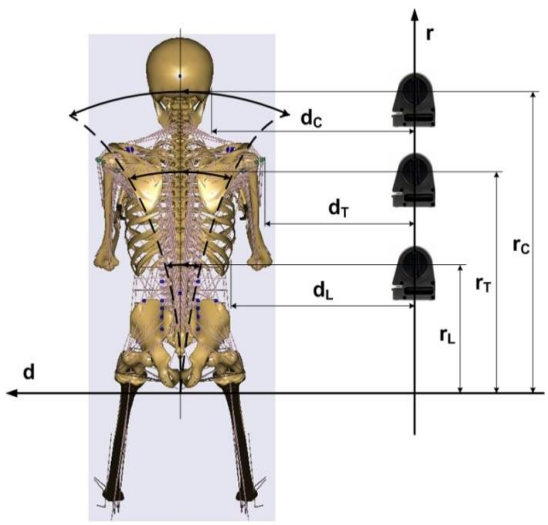

Fig. 11. Points of interest for sensor positioning.

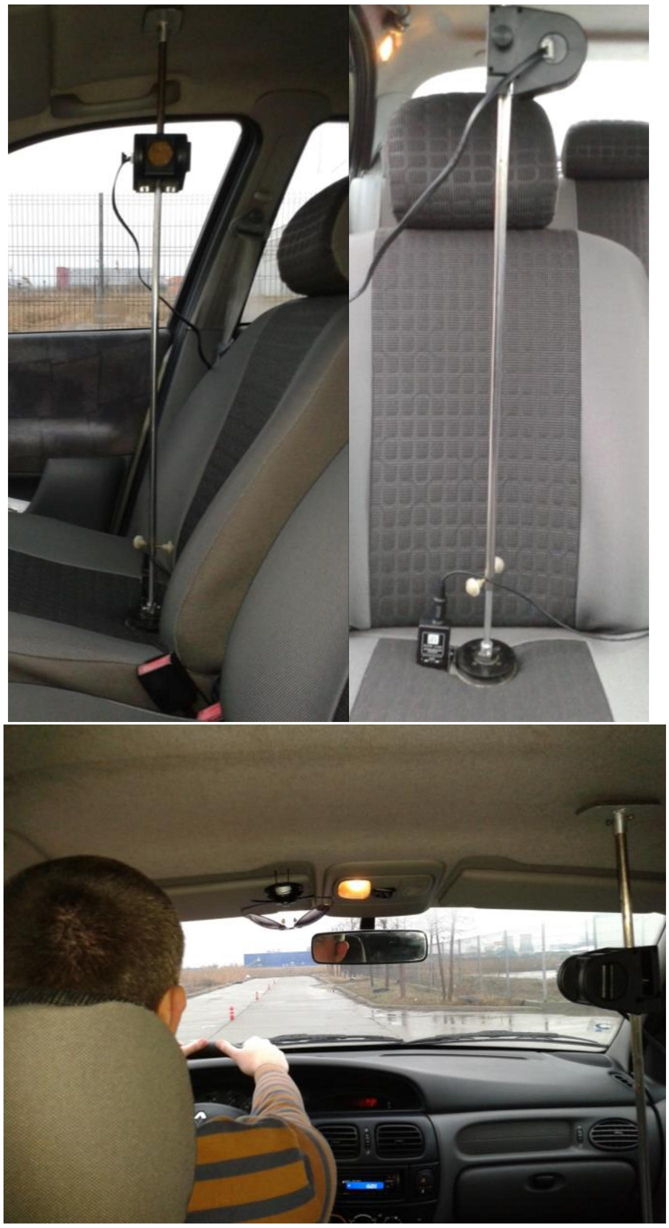

Fig. 12. The sensor in the first position for determining the C1 vertebra movements.

IV. The Experimental Results and Data Processing

The traveling time in one direction and performing a series of measurements, is about 15s.

Figures 13, 14 and 15 are presented graphically the results of series of measurements for the three points. At each step corresponding to a point were performed seven series of measurements.

For each point were averaged seven sets of measurements. Thus the results of processing experimental data are presented graphically in figure 16.

As a first analysis of the results obtained, it can be seen that the variation in time of the position of the three points can be expressed as a sinusoidal function with the same frequency but different amplitudes.

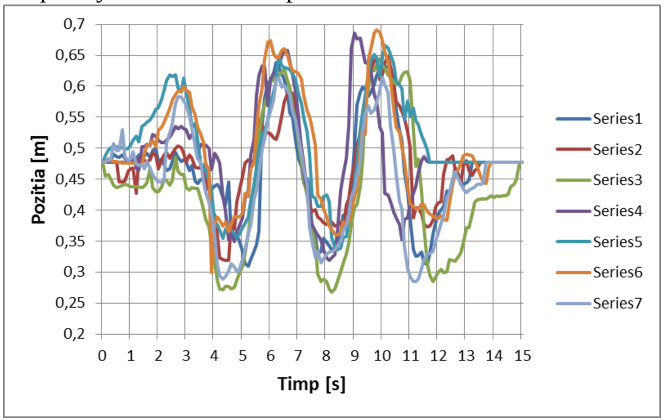

Fig. 13 - The series of measurements for the C1 vertebra.

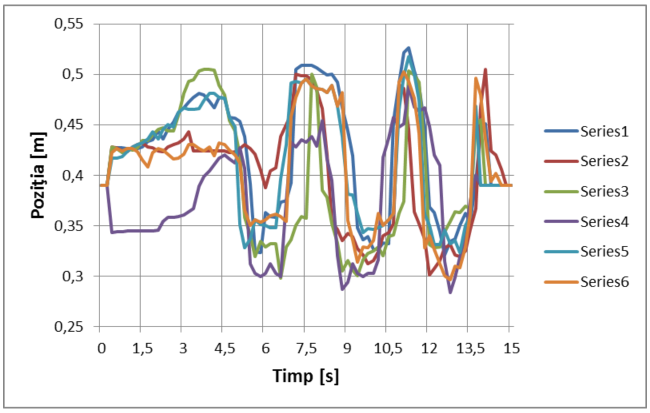

Fig. 14 - The series of measurements the T4 vertebra.

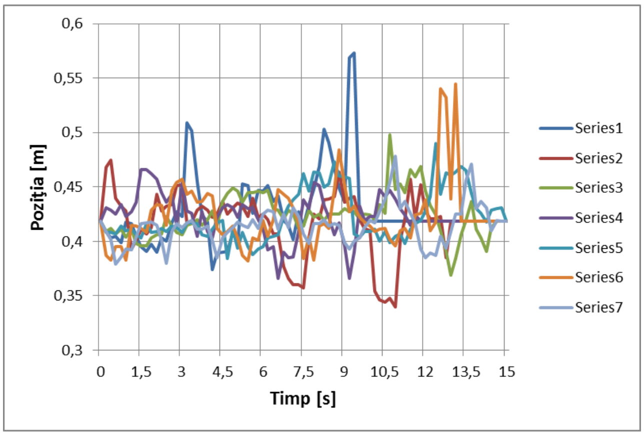

Fig. 15 - The series of measurements for the L1 vertebra.

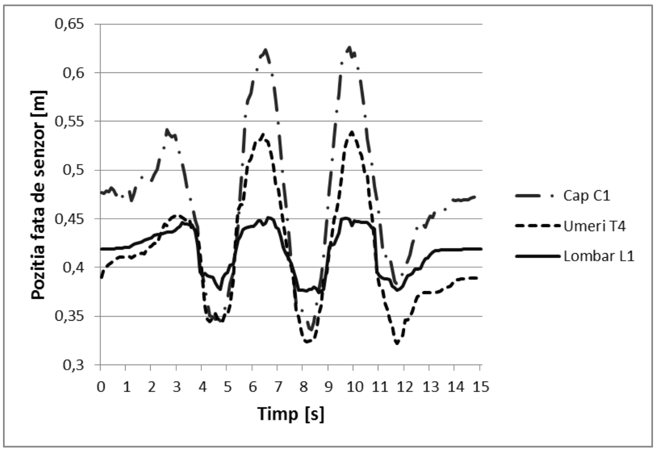

Fig. 16 – Graphical representation of the positions in time of the three points.

V. Determination of the Sinusoidal Functions Describing the Variation in Time of the C1, T4 and L1 Vertebras Positions

Using the Mathcad software the position in time values for the three points were introduced as the following strings:

cp :=

	0
0	0.477
1	0.476
2	0.479
3	0.478
4	0.482
5	0.479
6	0.474
7	0.48
8	0.473
9	0.473
10	0.475
11	0.48
12	0.469
13	0.476
14	0.485
15	...

um :=

	0
0	0.39
1	0.399
2	0.401
3	0.403
4	0.405
5	0.407
6	0.409
7	0.411
8	0.411
9	0.411
10	0.411
11	0.411
12	0.41
13	0.412
14	0.413
15	...

lb :=

	0
0	0.418
1	0.418
2	0.418
3	0.419
4	0.419
5	0.419
6	0.419
7	0.42
8	0.42
9	0.42
10	0.42
11	0.421
12	0.422
13	0.424
14	0.425
15	...

The *cp* string corresponds to the C1 point, *um* string corresponds to the T4 point and *lb* string corresponds to the L1 point.

The next step is to determine the frequency of each string.

$$tcpmax_i := \begin{cases} i & \text{if } max(cp) = cp_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tcpmax) = 98$$

$$tcpmin_i := \begin{cases} i & \text{if } min(cp) = cp_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tcpmin) = 83$$

$$tummax_i := \begin{cases} i & \text{if } max(um) = um_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tummax) = 99$$

$$tummin_i := \begin{cases} i & \text{if } min(um) = um_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tummin) = 117$$

$$tlbmax_i := \begin{cases} i & \text{if } max(lb) = lb_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tlbmax) = 70$$

$$tlbmin_i := \begin{cases} i & \text{if } min(lb) = lb_i \\ 0 & \text{otherwise} \end{cases}$$

$$max(tlbmin) = 86$$

The time interval between the maximum and minimum for each string is determined:

$$\Delta tcp = \frac{|max(tcpmax) - max(tcpmin)|}{10} = 1.5s \quad (4)$$

$$\Delta tum = \frac{|max(tummax) - max(tummin)|}{10} = 1.8s \quad (5)$$

$$\Delta tlb = \frac{|max(tlbmax) - max(tlbmin)|}{10} = 1.6s \quad (6)$$

In order to determine the single frequency in all three strings, the average of the three time periods is determined:

$$\Delta t = \frac{\Delta tcp + \Delta tum + \Delta tlb}{3} = 1.6333s \quad (7)$$

Thus, the frequency will be:

$$f_{\Delta t} = \frac{1}{\Delta t} \quad (8)$$

The amplitude of each string is determined as follows:

$$acp = \frac{max(cp) + min(cp)}{2} \quad (9)$$

$$aum = \frac{max(um) + min(um)}{2} \quad (10)$$

$$alb = \frac{max(lb) + min(lb)}{2} \quad (11)$$

The *cp* string amplitude is noted *acp*, the *um* string amplitude is noted with *aum*, and the amplitude of the *lb* string is noted *alb*.

The sinusoidal functions describing the position variation in time of the C1, T4 and L1 vertebraes points are the following:

$$ycp_i = cp_0 + acp \cdot cos(f_{\Delta t} \cdot i \cdot \pi) \quad (12)$$

$$yum_i = um_0 + aum \cdot cos(f_{\Delta t} \cdot i \cdot \pi) \quad (13)$$

$$ylb_i = lb_0 + alb \cdot cos(f_{\Delta t} \cdot i \cdot \pi) \quad (14)$$

In the figures 17, 18 and 19 the sinusoidal functions are represented in comparison to the *cp*, *um* and *lb* strings graphic form. For each case can be seen that the sinusoidal functions allure is very close to the allure of the strings measured values.

In conclusion it can be considered that these sinusoidal functions can describe the position variation in time of the C1, T4 and L1 vertebra's points, while driving on a sinusoidal trajectory.

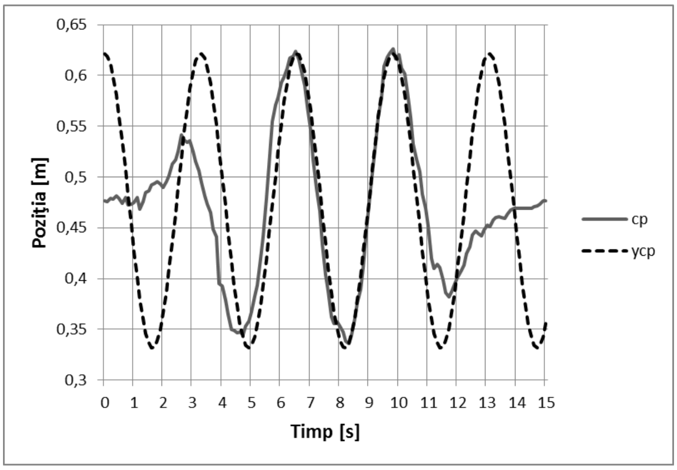

Fig. 17 - Graphical representation of the *ycp* sinusoidal function compared with the *cp* string.

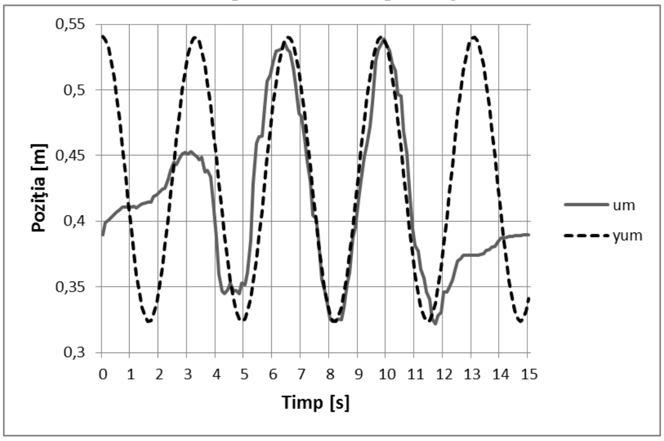

Fig. 18 - Graphical representation of the *yum* sinusoidal function compared with the *um* string.

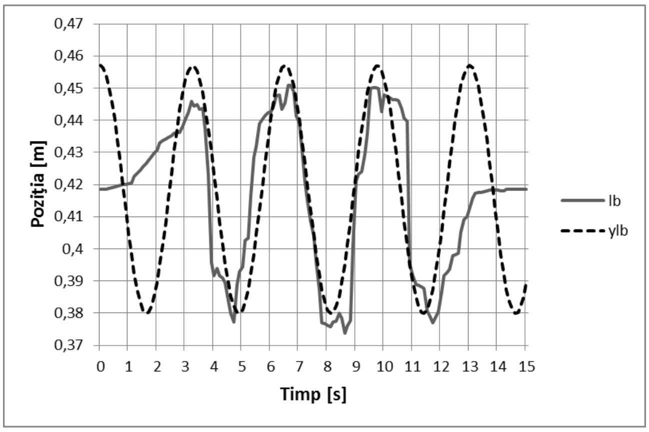

Fig. 19 - Graphical representation of the *ylb* sinusoidal function compared with the *lb* string.

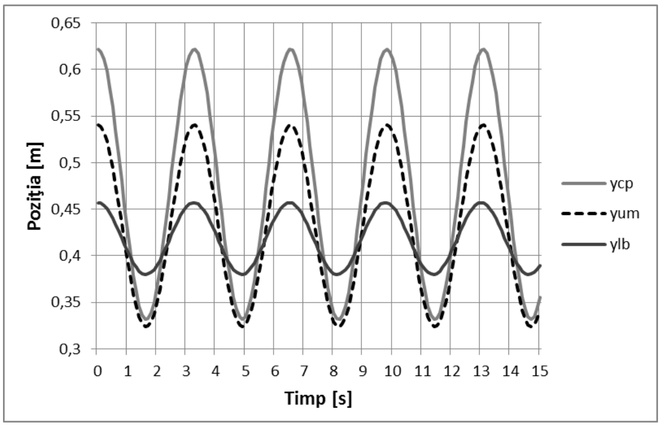

Fig. 20 – The sinusoidal functions describing the position variation in time of the C1, T4 and L1 vertebras points.

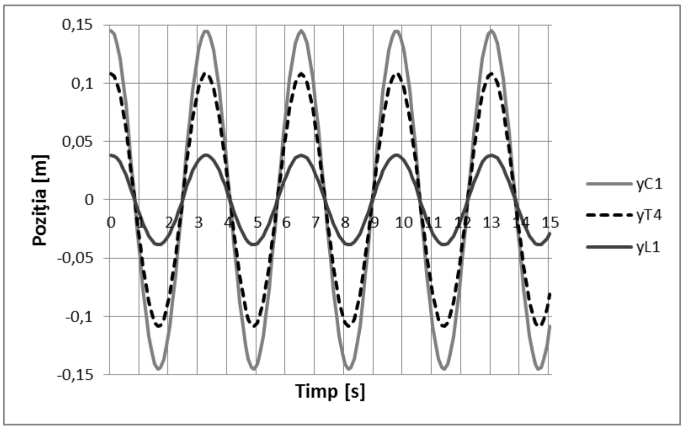

Fig. 21 – The sinusoidal functions describing the position variation in time of the C1, T4 and L1 vertebras.

The sinusoidal functions describing the position variation in time of the C1, T4 and L1 vertebras in the coronal plane are:

$$yC1_i = acp \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (15)$$

$$yT4_i = aum \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (16)$$

$$yL1_i = alb \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (17)$$

VI. Conclusions

The amplitude values of the sinusoidal functions describing the variation in time of angles between the vertebras gives an image regarding the deformation degree of the intervertebral discs.

A nonergonomic posture of the driver's body seated in the vehicle's seat implies the spine to be in a shape that subjects the intervertebral discs to uneven tensions causing deformations that in some cases can exceed the limits at which the musculoskeletal affections of the spine can be avoided or treated by physiotherapy.

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